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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

MYOPIC SEARCH PLANS

by

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Antonio Francisco de Paula Neto

September 1978

Thesis Advisor: A. R. Washburn

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(20. ABSTRACT Continued)

This thesis documents interactive computer programs that are useful for testing search strategies against the myopic strategy, and shows examples where the myopic strategy is not optimal.

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Myopic Search Plans

by

Antonio Francisco de Paul Neto
Lieutenant Commander, Brazilian Navy
Graduate, Brazilian Naval Academy, 1964

Submitted in partial fulfillment of the
requirements for the degree of

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from the

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September 1978

Author

Approved by: Thesis Advisor

Second Reader

Chairman, Department of Operations Research

Dean of Information and Policy Sciences

ABSTRACT

Different strategies can be used to search for a moving object.

If the searcher's action at each time unit maximizes his chances of immediate detection, his strategy is said to be myopic. If, however, the searcher seeks to allocate search effort to maximize the probability of detecting the traget within a preset amount of time, his strategy is called optimal.

This thesis documents interactive computer programs that are useful for testing search strategies against the myopic strategy, and shows examples where the myopic strategy is not optimal.

TABLE OF CONTENTS

I. INTRODUCTION

A search is an operation with the purpose of finding an object (target) that will in the thesis be assumed to move during the search.

In general, it will be assumed that the target is within an area that can be partitioned into a finite number of cells, moving from one cell to another at fixed time intervals (periods). The actual path that the object follows, whenever it moves, is unknown but the probabilistic distribution of all possible paths is given. It is assumed that the cells which the target will occupy in the future depend only on the cell it is in at the present time but not on how it got there (markovian motion).

If the searcher allocates his resources to maximize the chances of immediate detection, his search plan is said to be myopic. If, however, he seeks to allocate search effort to maximize the probability of detection within a preset amount of time, his plan is called optimal.

In an important class of naval search problems, the target probabilistic distribution over space, i.e., the initial probability of it being in each cell is known. If resources are allocated to some cells, a new distribution over space is to be considered after an unsuccessful search, according to Bayes' theorem.

Formally, it is assumed that the following are given:

a) A set C of states.

b) A set A of actions.

c) *An apriori distribution* $P_1(c)$ defined on C with $P_1(c)$ being the probability that the target is initially in state c.

d) A function $Q(a,c)$ being the probability of no detection if action a is taken when target is in state c.

e) A function $M(c/d)$ being the probability that the state of the target changes from d to c between actions. Since only the current state d is relevant to determine c, the target motion is markovian.

Let $a_1, a_2, \ldots, a_t$ be a sequence of actions.

Let $P'_t(c)$ be the probability distribution of the state of the target conditioned on non-detection by $a_1, a_2, \ldots, a_t$ and t-1 state changes, and $P_{t+1}(c)$ be the probability distribution conditioned on non-detection by $a_1, a_2, \ldots, a_t$ and t state changes.

Then, according to Bayes theorem,

$$P'_t(c) = \frac{P_t(c)Q(a_t,c)}{\sum_d P_t(d)Q(a_t,d)} \qquad (1)$$

and according to the motion model

$$P_{t+1}(c) = \sum_d P'_t(d)M(c/d) \qquad (2)$$

Since $P_1(c)$ is given, alternative applications of (1) and (2) will provide $P_t(c)$ for all t.

The probability of detection during period t, conditioned on earlier failures is

$$P_t = \sum_d P_t(d)[1 - Q(a_t,d)]$$

If a_t is chosen to maximize P_t for t = 1,2, ... in succession, then a_t is a myopic plan.

The probability that the target has not been detected until the end of the T^{th} period is

$$\overline{P}(T) = P[\text{target not detected at period 1, and not detected at period 2, and ..., and not detected at period T}]$$

$$\overline{P}(T) = \prod_{t=1}^{T} (1 - P_t) = \prod_{t=1}^{T} [\sum_d P_t(d)Q(a_t,d)]$$

Then, the probability of detection after T actions

$$P(T) = 1 - \overline{P}(T) = 1 - \prod_{t=1}^{T} [\sum_d P_t(d)Q(a_t,d)]$$

a_t is an optimal plan if it maximizes P(T) for a given T.

Optimal plans are highly complex and consequently expensive to find [1]. In contrast, myopic plans are easy to find.

The myopic strategy may be optimal, as in the case of stationary targets, or near optimal, as in most of the examples in references [1] and [2].

There are however, cases for which myopic plans are strongly non-optimal.

Models are to be constructed and used to reach the main goals of this thesis:

1) Develop and implement an algorithm to find myopic plans.

2) Create interactive search programs, and

3) Use them to discover classes of problems for which the myopic strategy is strongly non-optimal.

II. THE MODELS AND ASSUMPTIONS

A. SPACE MODEL

Space is divided into mxn square cells, each one identified by a 2-tuple. The upper left cell is cell (1,1). Cell (i,j) is the i^{th} cell to the east, j^{th} cell to the south.

If it happens that a target cannot move in some directions, boundaries can be introduced, either reflecting or absorbing. A target cannot cross a reflecting boundary. If one of its paths leads to the outside, this path is reflected, i.e., the target moves in the opposite direction. Reflecting boundaries model, for example, the borders of a channel. An absorbing boundary can be crossed from the interior but not from outside. It models the case in which the target has some information about the search area and tries to evade. Once it is out, it will never move back into that area.

By search area it is meant the subset of cells to which the searcher is able, allowed or willing to allocate effort and that is not necessarily the same subset that the target can move across. The latter will be referred to as the target area.

B. DETECTION MODEL

Sensors are assumed to have an exponential detection function, that is, the conditional probability of detection has the form:

$$1 - \exp[-a(g,t)x(g,t)],$$

where $x(g,t)$ is the amount of search effort allocated to cell g at period t and $a(g,t)$ is a non-negative constant which may depend on the cell, may change with time, and that will be referred to as detection rate.

C. THE MOTION MODELS

Two models are used: the random walk in space and the random walk in speed.

In both models, speed is expressed in terms of cells per period.

If a target occupies cell (i,j) and, after a change of state it is in cell $(i+k,j+\ell)$, its speed in the west-east direction is $V_x = k$ cells/period, and its speed in the north-south direction is $V_y = \ell$ cells/period

1. Random Walk in Space

In this model, $P_t(c) = S_t(i,j)$, i.e., $P_t(c)$ is the probability of the target being in cell (i,j).

Given the joint distribution of V_x and V_y, $t_{V_x,V_y}(v_x,v_y)$, invariant with time and space,

$$S_{t+1}(i,j) = \sum_k \sum_\ell S_t(k,\ell)\, t_{V_x,V_y}(i-k,j-\ell)$$

The, for this model,

$$M(c/d) = t_{V_x,V_y}(i-k,j-\ell)$$

where i and j define state c, and the state d is defined by k and ℓ.

2. <u>Random Walk in Speed</u>

Sets of possible values for V_x and V_y are fixed.

Let $V^x = \{v_1^x, v_2^x, \ldots, v_n^x\}$ and $V^y = \{v_1^y, v_2^y, \ldots, v_m^y\}$ be the sets of possible values that V_x and V_y can assume. $P_t(c)$ is equal to $S_t(i,j,k,\ell)$, i.e., $P_t(c)$ is the probability of the target being in cell (i,j), its speed having components, v_k^x, v_ℓ^y.

Let $P_{\Delta V_x}(\delta V_x)$ and $P_{\Delta V_y}(\delta V_y)$ be the known discrete distributions of ΔV_x and ΔV_y, the changes in V_x and V_y per period, respectively.

Given $P_{\Delta V_x}(\delta V_x)$ a matrix P^x can be constructed, which entries $p_{i,j}^x$ are the probabilities of V_x changing from v_i^x to v_j^x in one period. A similar matrix P^y can be constructed which entries are the probabilities of the changes in V_y. Then

$$S_{t+1}(i,j,k,\ell) = \sum_r \sum_s S_t(i-r,j-s,r,s)\, p_{r,k}^x\, p_{s,\ell}^y .$$

III. MYOPIC SEARCH PLANS

Let p_i, $i = 1,2, \ldots, n$ be the probability of the target being in the i^{th} of the n cells among which the search effort is to be myopically distributed at period t.

Let x_i, $i = 1,2, \ldots, n$ be the fraction of effort allocated to each of the cells that are assumed to have a common detection rate a which may change with periods.

Given the detection model, a myopic plan maximizes

$$\sum_i p_i(1 - e^{-ax_i}) \ , \quad i = 1,2, \ldots, n$$

for each $t = 1,2, \ldots$ in *succession*.

The sum of all x_i must not exceed X, the total amount of effort available in the period and no x_i can be less than 0.

Thus, a myopic plan is the solutions of a sequence of non-linear programs with the form

$$\text{Min} \quad \sum_i p_i e^{-ax_i} \tag{1}$$

$$\text{S/T} \quad \sum_i x_i \leq X \tag{2}$$

$$x_i \geq 0 \ , \quad i = 1,2, \ldots, n \tag{3}$$

It can be easily proved that equality holds for (2) at optimality.

If the constraints (3) are relaxed and Lagrange method is used:

$$L(x,\lambda) = \sum_i p_i e^{-ax_i} + \lambda(\sum_i x_i - X)$$

$$\frac{\partial L}{\partial x_i} = -ap_i e^{-ax_i} = 0 \tag{4}$$

$$\frac{\partial L}{\partial \lambda} = \sum_i x_i - X = 0 \tag{5}$$

From (4)

$$\lambda = ap_i e^{-ax_i}$$

$$\ln \lambda = \ln(ap_i) - ax_i \tag{6}$$

$$x_i = \frac{\ln a}{a} + \frac{\ln p_i}{a} - \frac{\ln \lambda}{a} \tag{7}$$

Sum (6), side by side, over all i:

$$n \ln \lambda = \sum_i \ln(ap_i) - a \sum_i x_i \tag{8}$$

Substitute X for $\sum_i x_i$ in (8) and rearrange:

$$\ln \lambda = \ln a + \frac{1}{n} \ln[\prod_i p_i] - \frac{aX}{n} \tag{9}$$

Substitute (9) for $\ln \lambda$ in (7):

$$x_i^* = \frac{\ln a}{a} + \frac{\ln p_i}{a} - \frac{1}{a}[\ln a + \frac{1}{n}\ln(\prod_i p_i) - \frac{aX}{n}]$$

$$x_i^* = \frac{\ln p_i}{a} - \frac{1}{an} \ln[\prod_i p_i] + \frac{X}{n}, \quad i = 1,2, \ldots, n \tag{10}$$

Brown [2] proved that the objective function is convex. Then (10) is the optimal solution of the N.L.P. (1), (2). At optimality,

$$p_i e^{-ax_i} = \frac{\lambda}{a} = \text{constant for } i = 1,2, \ldots, n .$$

A. ALGORITHM FOR FINDING MYOPIC PLANS

Provided the detection rate is invariant with cells:

Step 1) Let $I = \{i: i = 1,2, \ldots, n\}$ be the set of indexes of all cells among which the search effort is to be myopically distributed.

Step 2) Solve the N.L.P. (1), (2):

$$x_i = \frac{\ln p_i}{a} + \frac{X}{m} - \frac{\ln P}{am}, \quad i \in I$$

where $P = \prod_{i \epsilon I} p_i$ and m is the number of elements in I.

If $x_i \geq$ for all $i \epsilon I$, stop.

Step 3) Select the cell with smallest p_i, $i \epsilon I$. Remove its index from I and make $x_i = 0$

Go to step 2.

At optimality, $p_j \leq p_i e^{-ax_i^*}$ = constant, for all $j \not\in I$, all $i \epsilon I$.

The algorithm has at most n interactions. It solution is feasible for the N.L.P. (1), (2), (3) since

$$x_i^* = 0 \quad i \not\in I$$

$$x_i^* \geq 0 \quad i \epsilon I$$

$$\sum_i x_i = X$$

and is also optimal.

Let $Z^* = p_1 + p_2 + \ldots + p_j + p_{j+1}e^{-ax_{j+1}} + \ldots + p_{j+m}e^{-ax_{j+m}}$

where $j+m = n$, be the optimal solution produced by the algorithm after reindexing the cells such that $p_i < p_{i+1}$ for all i.

Then, the algorithm found

$$x_j = \frac{\ln p_j}{a} + \frac{X}{m+1} - \frac{\ln P'}{a(m+1)} \leq 0 \qquad (11)$$

where

$$P' = \prod_{i=j}^{j+m} p_i \ .$$

Suppose the optimal solution was

$$\hat{Z}^* = p_1 + p_2 + \ldots + p_{j-1} + p_j e^{-ax'_j} + p_{j+1} e^{-ax'_{j+1}}$$

$$+ \ldots + p_{j+m} e^{-ax_{j+m}} \ .$$

In this case,

$$p_j e^{-ax'_j} = p_{j+1} e^{-ax'_{j+1}} = \ldots = p_{j+m} e^{-ax'_{j+m}}$$

and

$$\ln p_j - ax'_j = \ln p_{j+1} - ax'_{j+1}$$

$$\ln p_j - ax'_j = \ln p_{j+2} - ax'_{j+2}$$

$$\vdots$$

$$\ln p_j - ax'_j = \ln p_{j+m} - ax'_{j+m}$$

Sum side by side:

$$m \ln p_j - amx'_j = \sum_{i=j+1}^{j+m} \ln p_i - a \sum_{i=j+1}^{j+m} x'_i$$

$$m \ln p_j - a(m+1)x'_j = \ln\left(\prod_{i=j+1}^{j+m} p_i\right) - aX$$

$$x'_j = \frac{m \ln p_j}{a(m+1)} + \frac{X}{(m+1)} - \frac{\ln P}{a(m+1)} > 0 \qquad (12)$$

where

$$P = \prod_{i=j+1}^{j+m} p_i$$

Compare (11) and (12):

$$\frac{m \ln p_j}{a(m+1)} + \frac{X}{(m+1)} - \frac{\ln P}{a(m+1)} > \frac{\ln p_j}{a} + \frac{X}{(m+1)} - \frac{\ln P'}{a(m+1)}$$

Since $a(m+1) > 0$

$$m \ln p_j - \ln P > (m+1) \ln p_j - \ln P'$$

$$\ln P' - \ln P > \ln p_j$$

$$\ln \frac{P'}{P} > \ln p_j$$

$$\ln p_j > \ln p_j \qquad (13)$$

Since no x_i can be made 0 before x_{i-1}, (13) proves by contradiction that the solution is optimal.

IV. THE COMPUTER PROGRAMS

Two FORTRAN programs were written.

Program SRCH1 refers to the random walk in space model and allows the space to be divided into a maximum of 100 x 100 cells. Any subset of cells can be used as target and/or search areas.

In this program, a two dimensional array is defined by the FORTRAN name CELL, which entries are the probabilities of the target being in each of the cells identified by the array indexes.

Program SRCH2 refers to the random walk in speed model. A 25 x 25 x 4 x 4 array is defined by the FORTRAN name CELL. The entries of this array are the probabilities of the target being in the cells identified by the first two indexes, its speed having the components defined by the last two indexes. Thus, this program allows the space to be divided into a maximum of 25 x 25 cells and allows the sets of possible values of V_x and V_y to have at most 4 elements each. Any subset of cells can be used as target and/or search areas.

SRCH2 maps the four dimensional array into a two dimensional array called TCELL, which entries have the same meaning as the entries of the array CELL in program SRCH1.

These two dimensional arrays are printed at the beginning of each period, after their entries are coded as follows:

The highest probability is mapped onto 100; the smallest non-zero probability mapped onto 0.

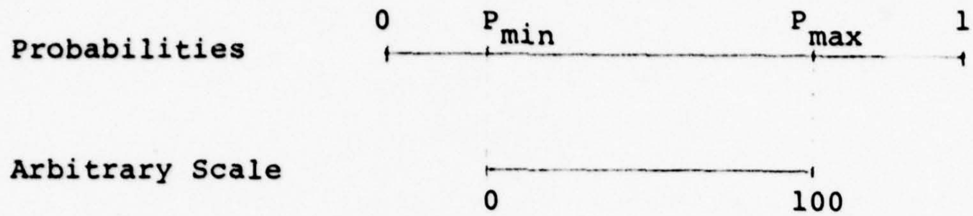

Fig. IV-1

The interval [0,100] is then divided and coded.

Subinterval	Code
100	*
[99,100)	9
[96,99)	8
[91,96)	7
[84,91)	6
[75,84)	5
[64,75)	4
[51,64)	3
[36,51)	2
[19,36)	1
[0,19)	0

Probabilities equal 0 are coded as a dot. Fig. IV-2 is an example of the coded distribution of the target.

```
RANGE OF PROBABILITIES  0.29119E-07  0.17087E-01

     30        40        50

      0123456789012345678901234

      -------------------------

27/   0000000000000000000000000
28/   0000000000000000000000000
29/   0000000011111111100000000
30/   0000001122233322211000000
31/   0000011223333333221100000
32/   0000012234444444322100000
33/   0000012345677765432100000
34/   000000124578*875421000000
35/   0000000123455543210000000
36/   .00000001122222110000000.
37/   ..000000000000000000000..
38/   ...0000000000000000000...
39/   ....00000000000000000....
40/   .....000000000000000.....
```

Fig. IV-2

Both programs have a subroutine that distributes myopically the search effort, provided the detection rate is invariant with space within the search area.

Instructions on use of the programs constitute Appendices A and B.

V. EXAMPLES AND CONCLUSIONS

A. EXAMPLES

Different situations were analysed and some of them are now presented.

1. First Example

The a priori distribution of a target was uniform over a 3 x 3 cell area as follows:

	30	31	32
30	1/9	1/9	1/9
31	1/9	1/9	1/9
32	1/9	1/9	1/9

The search areas was coincident with the above area and the target area was the entire space.

The target moved as follows:

V_x	V_y	$P(V_x=v_x, V_y=v_y)$
1	0	0.25
1	1	0.50
0	1	0.25

Five units of search effort were available and the detection rate was one for the cells within the search area, both values invariant with time.

A myopic and an alternative strategy were used which distributed effort as follows:

PERIOD 1

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(30,30)	0.5556	-
(31,30)	0.5556	-
(32,30)	0.5556	1.0
(30,31)	0.5556	-
(31,31)	0.5556	-
(32,31)	0.5556	1.0
(30,32)	0.5556	1.0
(31,32)	0.5556	1.0
(32,32)	0.5556	1.0

PERIOD 2

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(32,30)	-	0.313
(31,31)	1.25	-
(32,31)	1.25	1.527
(30,32)	-	0.313
(31,32)	1.25	1.527
(32,32)	1.25	1.32

PERIOD 3

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(31,31)	0.6781	-
(32,31)	1.4071	1.567
(31,32)	1.4071	1.526
(32,32)	1.5076	1.907

PERIOD 4

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(32,31)	1.4331	1.4241
(31,32)	1.4331	1.3205
(32,32)	2.1337	2.2554

PERIOD 5

	STRATEGY	
CELL	MYOPIC	ALTERNATIVE
(32,32)	5.0	5.0

The probabilities of detection were, after each period were:

	STRATEGY	
PERIOD	MYOPIC	ALTERNATIVE
1	0.42624	0.35118
2	0.60819	0.56827
3	0.65128	0.69634
4	0.65790	0.71282
5	0.65814	0.71338

After 5 periods the alternative plan yielded a probability of detection 8.39% higher. This alternative strategy consisted in distributing myopically the effort among the cells adjacent to the boundaries of the search area in the direction of the movement of the target. It made a barrier that the target had to cross to leave the search area.

This example suggested that myopic strategy was strongly non-optimal for cases in which the target could move to a safe region, and the search lasted long enough for it to reach this region.

This example led to the hypothesis that myopic plans were also strongly non-optimal in situations where the target moved to areas where the conditional probability of detection was a strong function of space, the aforementioned example being the extreme case of conditional probability of detection equal zero. However, for other analysed problems, in which the target could also evade to a safe area, no strategies could be found that led to a probability of detection

as much as 4% higher than the probability produced by myopic strategies.

2. <u>Second Example</u>

The a priori distribution of a target was uniform over a 5 x 4 cell area as follows:

	40	41	42	43	44
22	0.05	0.05	0.05	0.05	0.05
23	0.05	0.05	0.05	0.05	0.05
24	0.05	0.05	0.05	0.05	0.05
25	0.05	0.05	0.05	0.05	0.05

The target area was the subset of cells (i,j) such that $38 \leq i \leq 40$, and the search area was such that $j \leq 28$.

The target moved as follows:

v_x	v_y	$P(V_x=v_x, V_y=v_y)$
-1	1	0.3
0	1	0.4
1	1	0.3

Five units of search effort were available and the detection rate was one for the cells within the search area, both values invariant with time.

The interesting point about this case is that four different strategies turned out to be better than the myopic for a seven peeriod search.

The strategies distributed effort as follows:

PERIOD 1

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(40,22)	0.2500	-	-	-	0.2500
(41,22)	0.2500	-	-	-	0.2500
(42,22)	0.2500	-	-	-	0.2500
(43,22)	0.2500	-	-	-	0.2500
(44,22)	0.2500	-	-	-	0.2500
(40,23)	0.2500	-	-	-	0.2500
(41,23)	0.2500	-	-	-	0.2500
(42,23)	0.2500	-	-	-	0.2500
(43,23)	0.2500	-	-	-	0.2500
(44,23)	0.2500	-	-	-	0.2500
(40,24)	0.2500	-	-	-	0.2500
(41,24)	0.2500	-	-	-	0.2500
(42,24)	0.2500	-	-	-	0.2500
(43,24)	0.2500	-	-	-	0.2500
(44,24)	0.2500	-	-	-	0.2500
(40,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(41,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(42,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(43,25)	0.2500	1.0000	1.0000	1.0000	0.2500
(44,25)	0.2500	1.0000	1.0000	1.0000	0.2500

PERIOD 2

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(40,23)	0.0360	-	-	-	0.0360
(41,23)	0.3927	-	-	-	0.3927
(42,23)	0.3927	-	-	-	0.3927
(43,23)	0.3927	-	-	-	0.3927
(44,23)	0.0360	-	-	-	0.0360
(40,24)	0.0360	-	-	-	0.0360
(41,24)	0.3927	-	-	-	0.3927
(42,24)	0.3927	-	-	-	0.3927
(43,24)	0.3927	-	-	-	0.3927
(44,24)	0.0360	-	-	-	0.0360
(40,25)	0.0360	0.7325	0.7325	0.7325	0.0360
(41,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(42,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(43,25)	0.3927	1.0892	1.0892	1.0892	0.3927
(44,25)	0.0360	0.7325	0.7325	0.7325	0.0360
(40,26)	0.0360				0.0360
(41,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(42,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(43,26)	0.3927	0.0892	0.0892	0.0892	0.3927
(44,26)	0.0360				0.0360

PERIOD 3

STRATEGY

CELL	MYOPIC	1	2	3	4
(40,24)	0.1406				0.1406
(41,24)	0.3229				0.3229
(42,24)	0.3229				0.3229
(43,24)	0.3229				0.3229
(44,24)	0.1406				0.1406
(39,25)		0.0304	0.0304	0.0304	
(40,25)	0.1406	0.7386	0.7386	0.7386	0.1406
(41,25)	0.3229	1.0448	1.0448	1.0448	0.3229
(42,25)	0.3229	1.1391	1.1391	1.1391	0.3229
(43,25)	0.3229	1.0448	1.0448	1.0448	0.3229
(44,25)	0.1406	0.7386	0.7386	0.7386	0.1406
(45,25)		0.0304	0.0304	0.0304	
(40,26)	0.1406	0.0168	0.0168	0.0168	0.1406
(41,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(42,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(43,26)	0.3229	0.0499	0.0499	0.0499	0.3229
(44,26)	0.1406	0.0168	0.0168	0.0168	0.1406
(40,27)	0.1406				0.1406
(41,27)	0.3229				0.3229
(42,27)	0.3229	0.0499	0.0499	0.0499	0.3229
(43,27)	0.3229				0.3229
(44,27)	0.1406				0.1406

PERIOD 4

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(39,25)		0.2006	-	-	-
(40,25)	0.1854	0.7037	-	-	-
(41,25)	0.2930	1.0049	-	-	-
(42,25)	0.2930	1.0944	-	-	-
(43,25)	0.2930	1.0049	-	-	-
(44,25)	0.1854	0.7037	-	-	-
(45,25)	-	0.2006	-	-	-
(39,26)	-	-	0.2259	-	-
(40,26)	0.1854	0.0109	0.3666	-	-
(41,26)	0.2930	0.0109	0.3666	-	-
(42,26)	0.2930	0.0109	0.3666	-	-
(43,26)	0.2930	0.0109	0.3666	-	-
(44,26)	0.1854	0.0109	0.3666	-	-
(45,26)	-	-	0.2259	-	-
(39,27)	-	-	0.0720	0.2624	-
(40,27)	0.1854	-	0.2691	0.4594	-
(41,27)	0.2930	0.0109	0.3666	0.5570	-
(42,27)	0.2930	0.0109	0.3666	0.5570	-
(43,27)	0.2930	0.0109	0.3666	0.5570	-
(44,27)	0.1854	-	0.2691	0.4595	-
(45,27)	-	-	0.0720	0.2624	-
(39,28)	-	-	-	-	0.4636
(40,28)	0.1854	-	0.0144	0.2048	0.7500
(41,28)	0.2930	-	0.2756	0.4661	0.8576
(42,28)	0.2930	-	0.3528	0.5432	0.8576
(43,28)	0.2930	-	0.2756	0.4661	0.8576
(44,28)	0.1854	-	0.0144	0.2048	0.7500
(45,28)	-	-	-	-	0.4636

PERIOD 5

		STRATEGY			
CELL	MYOPIC	1	2	3	4
(39,26)	0.1551	0.2487	0.3106	-	-
(40,26)	0.2537	0.2939	0.7002	-	-
(41,26)	0.2829	0.2939	0.9634	-	-
(42,26)	0.2829	0.2939	1.0515	-	-
(43,26)	0.2829	0.2939	0.9634	-	-
(44,26)	0.2537	0.2939	0.7002	-	-
(45,26)	0.1551	0.2487	0.3106	-	-
(39,27)	0.1551	0.1902	-	0.5414	-
(40,27)	0.2537	0.2567	-	0.6122	-
(41,27)	0.2829	0.2939	-	0.6524	-
(42,27)	0.2829	0.2939	-	0.6524	-
(43,27)	0.2829	0.2939	-	0.6524	-
(44,27)	0.2537	0.2567	-	0.6122	-
(45,27)	0.1551	0.1902	-	0.5414	-
(39,28)	0.1551	0.0326	-	0.1294	0.5131
(40,28)	0.2537	0.1804	-	0.0953	0.7177
(41,28)	0.2829	0.2687	-	0.0953	0.8357
(42,28)	0.2829	0.2939	-	0.0953	0.8668
(43,28)	0.2829	0.2687	-	0.0953	0.8357
(44,28)	0.2537	0.1804	-	0.0953	0.7177
(45,28)	0.1551	0.0326	-	0.1294	0.5131

PERIOD 6

CELL	MYOPIC	STRATEGY 1	2	3	4
(39,27)	0.3795	0.4157	0.5429	0.3880	-
(40,27)	0.3482	0.3398	0.5177	0.6928	-
(41,27)	0.3482	0.3398	0.5177	0.9198	-
(42,27)	0.3482	0.3398	0.5177	0.9987	-
(43,27)	0.3482	0.3398	0.5177	0.9198	-
(44,27)	0.3482	0.3398	0.5177	0.6928	-
(45,27)	0.3795	0.4157	0.5429	0.3880	-
(39,28)	0.3795	0.3851	0.2164	-	0.5516
(40,28)	0.3482	0.3398	0.1887	-	0.7049
(41,28)	0.3482	0.3398	0.1717	-	0.8167
(42,28)	0.3482	0.3398	0.1717	-	0.8535
(43,28)	0.3482	0.3398	0.1717	-	0.8167
(44,28)	0.3482	0.3398	0.1887	-	0.7049
(45,28)	0.3795	0.3851	0.2164	-	0.5516

PERIOD 7

CELL	MYOPIC	STRATEGY 1	2	3	4
(38,28)	0.1225	0.1376	0.1727	0.0748	
(39,28)	0.7748	0.7845	0.8073	0.7448	0.5815
(40,28)	0.6411	0.6312	0.6080	0.6721	0.7013
(41,28)	0.6411	0.6312	0.6080	0.6721	0.7996
(42,28)	0.6411	0.6312	0.6080	0.6721	0.8352
(43,28)	0.6411	0.6312	0.6080	0.6721	0.7996
(44,28)	0.6411	0.6312	0.6080	0.6721	0.7013
(45,28)	0.7748	0.7845	0.8073	0.7448	0.5815
(46,28)	0.1225	0.1376	0.1727	0.0728	

The probabilities of detection after each period were:

		STRATEGY			
PERIOD	MYOPIC	1	2	3	4
1	0.22119	0.15803	0.15803	0.15803	0.22119
2	0.38064	0.29861	0.29861	0.29861	0.38064
3	0.49071	0.43139	0.43139	0.43139	0.49071
4	0.57188	0.55845	0.49688	0.48977	0.55116
5	0.63270	0.62597	0.62012	0.54531	0.61063
6	0.67812	0.67652	0.67891	0.66582	0.66948
7	0.70635	0.70815	0.71475	0.72319	0.72790

Strategy 4 was 3.05% better than the myopic, for a seven period search. This strategy searched myopically for the target until it could possibly be in cells adjacent to the boundaries of search area, and then, as in the first example, concentrated the effort in those cells.

B. CONCLUSIONS

Although myopic strategy is strongly non-optimal for some specific cases, as the first example in this thesis and as the problem which Brown [2] called the Island Passage Problem, no classes of problems could be characterized for which a strategy could be found that was much better than the myopic.

Many researched problems, the presented examples inclusive, show that a strategy which may not be optimal but that concentrates the effort near the boundaries of the search area when

the target reaches these boundaries, produces better results than a myopic strategy.

It should be noted that no cases were considered in which the detection rate changed with cells within the search area and none of the alternative strategies used can be guaranteed to be optimal.

C. EXTENSIONS

Extensions can be brought into this thesis that may possibly lead to the characterization of classes of problems for which the myopic strategy is strongly non-optimal.

First, an algorithm to find optimal plans may be implemented and added to the computer programs.

Second, the restriction on the change of detection rate with cells within the search area may be removed from the myopic plan.

Further, other motion model as the fleeing datum [1] and the geometric memory motion [2] can be used.

Last, a detection model in which the conditional probability of detection is a function of the speed of the target can be constructed and used together with the random walk in speed model.

APPENDIX A

INSTRUCTIONS ON USE OF PROGRAM SRCH1

The first data the program requires are the limits of the target area and types of boundaries. They must have the form

aadwwwbbbxxxcccyyydddzzz.

QUANTITY	MEANING	REQUIREMENTS
aaa	West limit	$001 \leq aaa \leq 100$
bbb	East limit	$001 \leq bbb \leq 100$; $bbb > aaa$
ccc	North limit	$001 \leq ccc \leq 100$
ddd	South limit	$001 \leq ddd \leq 100$; $ddd > ccc$
www	Type of the	
xxx	boundary which	REF for reflecting
yyy	preceeds each of	ABS for absorbing
zzz	these quantities	

Next, the program asks for the limits of the search area. The entry must have the form

aaabbbcccddd

all quantities with the same meanings and fulfilling the same requirements as above.

Then, the transition matrix is to be introduced.

If the probability of the target moving from cell (m,n) to cell $(m+k, n+\ell)$ is p_i, enter

aaabbb __p__

where

aaa = k

bbb = ℓ

__p__ = p_i

enter one line for each i, after which, enter Ø.

$\sum_i p_i$ must be equal to 1.

__p__ was the format F10.8

The last entry before calculations begin is the a priori distribution of the target, which must have the form,

eeefff p

where eee and fff identify the cell where the target is with probability __p__ ≠ Ø.
Enter one line for each __p__, after which enter Ø. __p__ must fulfill the requirements previously stated. From this point on, all actions are repeated at each period.

The program prints a table similar to that in Fig. IV-2 which shows the coded distribution of the target at the beginning of the period, and then, asks for the total amount of effort available in the period and the detection rate. Use format 2F5.3 to introduce these values.

In case the user does not want a myopic distribution, the effort is to be distributed as follows:

eeefff   t

where eee and fff identify the cell where the amount t is placed.

Enter one line for each t $\neq 0$.

Summation of all t must add up to the total amount of effort available in the period.

t has the format F10.8.

Enter Ø after distributing the search effort.

Questions must be answered Yes (Y) or No (N) as in the following example:

```
 $ srchl
EXECUTION BEGINS...
 ENTER LIMITS OF TARGET AREA AND TYPE OF BOUNDARIES
>025ref030ref020abs025ref
 ENTER LIMITS OF SEARCH AREA
>025030001100
 ENTER TRANSITION MATRIX
>000-010.25
>0000010.25
>0010000.25
>-010000.25
>0
 ENTER A PRIORI DISTRIBUTION OF TARGET
>0260220.3
>0260230.4
>0270230.3
>0
 RANGE OF PROBABILITIES  0.30000    0.40000
        26
        67
        --
 22/ 0.
 23/ *0
 ENTER TOTAL EFFORT AND DETECTION RATE
>3.0001.000
 MYOPIC PLAN?
>Y
```

```
 WANT TO KNOW DISTRIBUTION OF EFFORT?
>Y
  CELL   EFFORT
 26  22  0.9041
 26  23  1.1918
 27  23  0.9041
 AFTER 1 PERIODS, PROB DET IS  0.63559
 WANT TO CONTINUE?
>Y
 RANGE OF PROBABILITIES   0.833333$-01  0.16667
     25
      5678
      ---
 21/ .0..
 22/ 00*.
 23/ 0*00
 24/ .00.
 ENTER TOTAL EFFORT AND DETECTION RATE
>3.0001.000
 MYOPIC PLAN?
>n
 ENTER DISTRIBUTION OF SEARCH EFFORT
>0270221.5
>0260231.5
>0
 AFTER 2 PERIODS, PROB DET IS  0.72995
 WANT TO CONTINUE?
>n
 WANT TO PLAY AGAIN?
>n
R; T=4.73/9.44 13.30.46
>
```

APPENDIX B

INSTRUCTIONS ON USE OF PROGRAM SRCH2

The first data the program requires are the limits of the target area and types of boundaries. They must have the form

aawwwbbxxxccyyyddzzz

QUANTITY	MEANING	REQUIREMENTS
aa	West limit	$01 \le aa \le 25$
bb	East limit	$01 \le bb \le 25$; $bb > aa$
cc	North limit	$01 \le cc \le 25$
dd	South limit	$01 \le dd \le 25$; $dd > cc$
www	Type of the	
xxx	boundary which	REF for reflecting
yyy	preceeds each of	ABS for absorbing
zzz	these quantities	

Next, the program asks for the limits of the search area. The entry must have the form

aabbccdd

All quantities with the same meanings and fulfilling the same requirements as above.

Then, the program asks how many different values V_x can assume. Any positive integer less than 5 can be introduced, according to Format I2.

Use the same format to introduce the values of V_x, one per line.

The same question is made with respect to V_y, and the same instructions used for V_x apply.

Next, the transition matrix of V_x is to be introduced. Type

$\underline{\underline{ee}}$ $\underline{p}$

where $\underline{\underline{ee}}$ is the value ΔV_x can assume with probability $\underline{p}$. Enter one line for each $\underline{p}$, after which, enter Ø. Summation of all $\underline{p}$ must be 1. $\underline{p}$ has the format F5.3.

The transition matrix for V_y is introduced in accordance with the same rules stated for V_x.

The last data before calculations begin is the a priori distribution of target, which must have the form

$\underline{\underline{ff}}\underline{\underline{gg}}\,\underline{p}$ $\underline{q_1}$ $\underline{q_2}$ ... $\underline{r_1}$ $\underline{r_2}$ ...

where $\underline{\underline{ff}}$ and $\underline{\underline{gg}}$ identify the cell where the target is with probability $\underline{p}$.

$\underline{q_1}$ $\underline{q_2}$ ... are the conditional distribution of V_x, i.e., the probabilities of V_x being v_1^x, v_2^x, ... given the target is in cell (ff,gg). The number of quantities $\underline{q}$ must be equal to the number of possible values that V_x can assume. The summation of all $\underline{q}$ must be 1. The quantities $\underline{r}$ are the conditional distribution of V_y.

The format for quantities $\underline{p}$, $\underline{q}$ and $\underline{r}$ is F5.3.

Enter one line for each $\underline{p} \neq 0$, after which enter Ø.

Summation of all $\underline{p}$ must be one, too.

From this point on, all actions are repeated at each period.

The program prints a table similar to that in Fig. IV-2 which shows the coded distribution of the target at the beginning of the period, and then, asks for the total amount of effort available in the period and the detection rate.

Use format 2F5.3 to introduce these values.

In case the user does not want a myopic distribution, the effort is to be distributed as follows:

ffgg t

where ff and gg identify the cell where the amount t is placed.

Enter one line for each t $\neq$ 0.

Summation of all t must add up to the total amount of effort available in the period.

t has the format F10.8

Enter Ø after distributing the effort

Questions must be answered Yes (Y) or No (N) as in the following example:

```
>$ srch2
EXECUTION BEGINS...
 ENTER LIMITS OF TARGET AREA AND TYPES OF BOUNDARIES
>10ref15ref01ref25ref
 ENTER LIMITS OF SEARCH AREA
>01250125
 HOW MANY VALUES CAN V(X) ASSUME?
>03
 ENTER THESE VALUES, ONE PER LINE
>-1
>00
>01
 HOW MANY VALUES CAN V(Y) ASSUME?
>04
 ENTER THESE VALUES, ONE PER LINE
>-1
>00
>01
>02
```

```
 ENTER TRANSITION OF V(X)
>-10.3
>000.4
>010.3
>0
 ENTER TRANSITION OF V(Y)
>010.8
>020.2
>0
 ENTER A PRIORI DISTRIBUTIONS
>12120.3000.4000.3000.3000.1000.2000.3000.400
>12130.4000.5000.2000.3000.6000.2000.1000.100
>13140.3000.4000.4000.2000.5000.3000.1000.100
>0
 RANGE OF PROBABILITIES  0.30000       0.4000
     12
      23
      --
 12/ 0.
 13/ *.
 14/ .0
 ENTER TOTAL EFFORT AND DETECTION RATE
>1.0001.000
 MYOPIC PLAN?
>Y
 WANT TO KNOW DISTRIBUTION OF EFFORT?
>Y
   CELL    EFFORT
  12  12   0.2374
  12  13   0.5251
  13  14   0.2374
 AFTER 1 PERIODS, PROB DET IS 0.2902
 WANT TO CONTINUE?
> Y
 RANGE OF PROBABILITIES  0.66667#-02  0.12667
     11
      1234
      ----
  11/ 000.
  12/ *23.
  13/ 3671
  14/ 3440
  15/ 0000
  16/ .000
 ENTER TOTAL EFFORT AND DETECTION RATE
>1.0001.000
 MYOPIC PLAN?
>n
 ENTER DISTRIBUTION OF SEARCH EFFORT
>11120.7
>13130.3
>0
 AFTER 2 PERIODS, PROB DET IS 0.3569
 WANT TO CONTINUE
>n
 WANT TO PLAY AGAIN?
>n
R; &=7.10/8.93 14.06.39
```

PROGRAM SRCH1

```
      COMMON CELL(100,100),EF(100,100),PAT(60),
     2            MAP(60,2),LIM(4),NAT(4),
     3            MAXX,MINX,MAXY,MINY
      DIMENSION NIMB(4)
      DATA LAB,LIB,LOB/1HY,3HREF,3HABS/
  100 FORMAT (2X,'ENTER LIMITS OF TARGET AREA AND TYPE OF BOUNDARIES')
 1010 FORMAT (2X,'ENTER LIMITS OF SEARCH AREA')
 1011 FORMAT (4I3)
  101 FORMAT (4(I3,A3))
  102 FORMAT (2X,'ENTER TRANSITION MATRIX')
  103 FORMAT (2I3,2F10.8)
  104 FORMAT (2X,'INVALID INPUT DATA')
  105 FORMAT (2X,'ENTER A PRIORI DISTRIBUTION OF TARGET')
 1050 FORMAT (2X,'ENTER TOTAL EFFORT AND DETECTION RATE')
 1051 FORMAT (F5.3,F5.3)
 1052 FORMAT (2X,'MYOPIC PLAN?')
  106 FORMAT (2X,'ENTER DISTRIBUTION OF SEARCH EFFORT')
  108 FORMAT (2X,'WANT TO CONTINUE?')
  109 FORMAT (A1)
  111 FORMAT (21X,I2,4X,'(',I2,',',I2,')')
  112 FORMAT (2X,'WANT TO PLAY AGAIN?')
  120 WRITE (6,100)
  122 READ (5,101) ((LIM(I),NAT(I)),I=1,4)
      IF ((LIM(1).GE.1).AND.(LIM(2).LE.100).AND.
     2    (LIM(3).GE.1).AND.(LIM(4).LE.100))
     3    GO TO 1020
      WRITE (6,104)
      GO TO 120
 1020 WRITE (6,1010)
      READ (5,1011) (NIMB(J),J=1,4)
      IF ((NIMB(1).GE.1).AND.(NIMB(2).LE.100).AND.(NIMB(3).GE.1).
     2    AND.(NIMB(4).LE.100)) GO TO 123
      WRITE (6,104)
      GO TO 1020
  123 TOTAL=0.
      DO 124 I=1,60
      MAP(I,1)=0
      MAP(I,2)=0
      PAT(I)=0.
  124 CONTINUE
      IT=1
      WRITE (6,102)
  125 READ (5,103) MAP(IT,1),MAP(IT,2),PAT(IT)
      IF ((MAP(IT,1).EQ.0).AND.(MAP(IT,2).EQ.0).AND.
     2    (PAT(IT).EQ.0.)) GO TO 127
      TOTAL=TOTAL+PAT(IT)
      IT=IT+1
      IF (IT.LE.60) GO TO 125
```

```
127 IF (ABS(TOTAL-1.).LE.0.0001) GO TO 129                                SEA00490
    WRITE (6,104)                                                         SEA00500
    GO TO 123                                                             SEA00510
129 CONTINUE                                                              SEA00520
133 TOTAL=0.                                                              SEA00530
    MAXX=0                                                                SEA00540
    MINX=100                                                              SEA00550
    MAXY=0                                                                SEA00560
    MINY=100                                                              SEA00570
    DO 137 I=1,100                                                        SEA00580
    DO 137 J=1,100                                                        SEA00590
    CELL(I,J)=0.                                                          SEA00600
137 CONTINUE                                                              SEA00610
    WRITE (6,105)                                                         SEA00620
141 READ (5,103) N,M,CELL(M,N)                                            SEA00630
    IF ((N.EQ.0).AND.(M.EQ.0).AND.(CELL(M,N).EQ.0.)) GO TO 147            SEA00640
    MAXX=MAX0(MAXX,N)                                                     SEA00650
    MINX=MIN0(MINX,N)                                                     SEA00660
    MAXY=MAX0(MAXY,M)                                                     SEA00670
    MINY=MIN0(MINY,M)                                                     SEA00680
    TOTAL=TOTAL+CELL(M,N)                                                 SEA00690
    GO TO 141                                                             SEA00700
147 IF (ABS(TOTAL-1.).LE.0.0001) GO TO 149                                SEA00710
    WRITE (6,104)                                                         SEA00720
    GO TO 133                                                             SEA00730
149 KOUNT=1                                                               SEA00740
    PC=1.                                                                 SEA00750
155 CALL TABLE                                                            SEA00760
    WRITE (6,1050)                                                        SEA00770
    READ (5,1051) AM,FAC                                                  SEA00780
    IF (FAC.LT.1.E-5) FAC=1.E-5                                           SEA00790
    WRITE (6,1052)                                                        SEA00800
    READ (5,109) IANS                                                     SEA00810
    IF (IANS.NE.LAB) GO TO 159                                            SEA00820
    CALL MYOPIC(AM,FAC,NIMB)                                              SEA00830
    GO TO 181                                                             SEA00840
159 DO 160 I=1,100                                                        SEA00850
    DO 160 J=1,100                                                        SEA00860
    EF(I,J)=0.                                                            SEA00870
160 CONTINUE                                                              SEA00880
    TOTAL=0.                                                              SEA00890
    WRITE (6,106)                                                         SEA00900
163 READ (5,103) N,M,EF(M,N)                                              SEA00910
    IF ((N.EQ.0).AND.(M.EQ.0).AND.(EF(M,N).EQ.0.)) GO TO 171              SEA00920
    TOTAL=TOTAL+EF(M,N)                                                   SEA00930
    GO TO 163                                                             SEA00940
171 IF (ABS(TOTAL-AM).LE.1.E-03) GO TO 181                                SEA00950
    WRITE (6,104)                                                         SEA00960
```

```
      GO TO 159
  181 CALL PROB (PG,KOUNT,FAC)
      WRITE (6,108)
      READ (5,109) IANS
      IF (IANS.NE.LAB) GO TO 189
      CALL UPDATE (LIB,LCB,IT,FAC)
      KOUNT=KOUNT+1
      GO TO 155
  189 WRITE (6,112)
      READ (5,109) IANS
      IF (IANS.NE.LAB) STOP
      GO TO 120
      END
```

```
      SUBROUTINE MYOPIC (A,FAC,NIMB)                                    SEA01100
      COMMON  CELL(100,100),EF(100,100),FAT(60),                        SEA01110
     2        MAP(60,2),LIM(4),NAT(4),                                  SEA01120
     3        MAXX,MINX,MAXY,MINY                                       SEA01130
      DIMENSION ICELL(100,100),NIMB(4)                                  SEA01140
      DATA INDIA/1HY/                                                   SEA01150
  101 FORMAT (2X,'WANT TO KNOW DISTRIBUTION OF EFFORT?')               SEA01160
  102 FORMAT (A1)                                                       SEA01170
  103 FORMAT (2X,'  CELL    EFFORT   ')                                 SEA01180
  104 FORMAT (2X,I3,1X,I3,2X,F6.4)                                      SEA01190
  200 DO 201 I=MINY,MAXY                                                SEA01200
      DO 201 J=MINX,MAXX                                                SEA01210
      ICELL(I,J)=0                                                      SEA01220
  201 CONTINUE                                                          SEA01230
  226 DO 231 I=MINY,MAXY                                                SEA01240
      DO 231 J=MINX,MAXX                                                SEA01250
      EF(I,J)=0.                                                        SEA01260
  231 CONTINUE                                                          SEA01270
  241 IMIN=0                                                            SEA01280
      JMIN=0                                                            SEA01290
      B=1.                                                              SEA01300
      N=0                                                               SEA01310
      PMIN=1.                                                           SEA01320
      IFLAG=0                                                           SEA01330
      DO 247 I=MINY,MAXY                                                SEA01340
      DO 247 J=MINX,MAXX                                                SEA01350
      IF ((CELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3)).OR.  SEA01360
     2   (I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))            SEA01370
     3 GO TO 247                                                        SEA01380
      IF ((CELL(I,J).GE.PMIN).OR.(IFLAG.EQ.1))GO TO 243                 SEA01390
      PMIN=CELL(I,J)                                                    SEA01400
      IMIN=I                                                            SEA01410
      JMIN=J                                                            SEA01420
  243 CONTINUE                                                          SEA01430
      IF ((CELL(I,J).LE.PMIN).AND.(IFLAG.EQ.1)) ICELL(I,J)=1            SEA01440
      IF (IFLAG.EQ.1) GO TO 247                                         SEA01450
      N=N+1                                                             SEA01460
      B=(B**(1./(FAC*FLOAT(N))))**((FAC*FLOAT(N-1)))                    SEA01470
      B=B*CELL(I,J)**(1./(FAC*FLOAT(N)))                                SEA01480
      REF=EXP(A/FLOAT(N))                                               SEA01490
      BEF=B/(PMIN**(1./FAC))                                            SEA01500
      IF (REF.GE.BEF) GO TO 247                                         SEA01510
      ICELL(IMIN,JMIN)=1                                                SEA01520
      IFLAG=1                                                           SEA01530
  247 CONTINUE                                                          SEA01540
      IF (IFLAG.EQ.0) GO TO 248                                         SEA01550
      GO TO 241                                                         SEA01560
  248 DO 251 I=MINY,MAXY                                                SEA01570
```

```
      DO 251 J=MINX,MAXX
      IF ((CELL(I,J).EQ.0.).OR.(ICELL(I,J).NE.0).OR.
     2    (I.LT.NIMB(3)).OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.
     3    (J.GT.NIMB(2))) GO TO 251
      FFCB=B**(FAC*FLOAT(N))
      EF(I,J)=(ALOG(CELL(I,J))/FAC)+(A/FLOAT(N))-
     2        (ALOG(PROB)/(FAC*FLOAT(N)))
  251 CONTINUE
      WRITE (6,101)
      READ (5,102) IPU
      IF (IPU.NE.INDIA) RETURN
      WRITE (6,103)
      DO 281 I=MINY,MAXY
      DO 281 J=MINX,MAXX
      IF (EF(I,J).EQ.0.) GO TO 281
      WRITE (6,104) J,I,EF(I,J)
  281 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TABLE                                                  SEA01770
      COMMON CELL(100,100),EF(100,100),FAT(60),                         SEA01780
     2             MAP(60,2),LIM(4),NAT(4),                             SEA01790
     3             MAXX,MINX,MAXY,MINY                                  SEA01800
      DIMENSION ICELL(100),IMBOL(15)                                    SEA01810
      DATA IMBOL/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,                       SEA01820
     2           1H8,1H9,1H*,1H.,1H-,1H /                               SEA01830
  100 FORMAT (2X,'RANGE OF PROBABILITIES',2(1X,G12.5))                  SEA01840
  101 FORMAT (2X,I3,'/ ',100A1)                                         SEA01850
  102 FORMAT (6X,I2,9(8X,I2))                                           SEA01860
  103 FORMAT (7X,100I1)                                                 SEA01870
  104 FORMAT (7X,100A1)                                                 SEA01880
      SMALL=1.                                                          SEA01890
      BIG=0.                                                            SEA01900
      DO 217 I=MINY,MAXY                                                SEA01910
      DO 217 J=MINX,MAXX                                                SEA01920
      IF ((CELL(I,J).NE.0.).AND.(CELL(I,J).LT.SMALL)) SMALL=CELL(I,J)   SEA01930
      IF (CELL(I,J).GT.BIG) BIG=CELL(I,J)                               SEA01940
  217 CONTINUE                                                          SEA01950
      WRITE (6,100) SMALL,BIG                                           SEA01960
      IF ((BIG-SMALL).LT.1.E-10) SMALL=0.                               SEA01970
      DO 417 I=1,100                                                    SEA01980
      ICELL(I)=MINX+(I-1)*10                                            SEA01990
      IF (ICELL(I).GT.MAXX) GO TO 418                                   SEA02000
  417 CONTINUE                                                          SEA02010
  418 I=I-1                                                             SEA02020
      WRITE (6,102) (ICELL(J),J=1,I)                                    SEA02030
      LA=MAXX-MINX+1                                                    SEA02040
      DO 517 N=1,LA                                                     SEA02050
      ICELL(N)=MOD(N-1+MINX,10)                                         SEA02060
  517 CONTINUE                                                          SEA02070
      WRITE (6,103) (ICELL(I),I=1,LA)                                   SEA02080
      DO 617 I=1,LA                                                     SEA02090
      ICELL(I)=IMBOL(13)                                                SEA02100
  617 CONTINUE                                                          SEA02110
      WRITE (6,104) (ICELL(I),I=1,LA)                                   SEA02120
      DO 817 I=MINY,MAXY                                                SEA02130
      DO 717 J=MINX,MAXX                                                SEA02140
       ICELL(J)=IMBOL(1+IFIX(10.                                        SEA02150
     2  -SQRT(100.-(CELL(I,J)-SMALL)/(BIG-SMALL)*100.)))                SEA02160
      IF (CELL(I,J).EQ.0.) ICELL(J)=IMBOL(12)                           SEA02170
  717 CONTINUE                                                          SEA02180
      WRITE (6,101) I,(ICELL(J),J=MINX,MAXX)                            SEA02190
  817 CONTINUE                                                          SEA02200
      RETURN                                                            SEA02210
      END                                                               SEA02220
```

```
      SUBROUTINE UPDATE (LIB,LOB,IT,FAC)                                SEA02230
      COMMON CELL(100,100),EF(100,100),PAT(60),                         SEA02240
     2              MAP(60,2),LIM(4),NAT(4),                            SEA02250
     3              MAXX,MINX,MAXY,MINY                                 SEA02260
      DENOM=0.                                                          SEA02270
      DO 318 I=1,100                                                    SEA02280
      DO 318 J=1,100                                                    SEA02290
      DENOM=DENOM+CELL(I,J)*EXP(-FAC*EF(I,J))                           SEA02300
  318 CONTINUE                                                          SEA02310
      DO 319 I=1,100                                                    SEA02320
      DO 319 J=1,100                                                    SEA02330
      CELL(I,J)=CELL(I,J)*EXP(-FAC*EF(I,J))/DENOM                       SEA02340
      EF(I,J)=0.                                                        SEA02350
  319 CONTINUE                                                          SEA02360
      CALL SPREAD (LIB,LOB,IT)                                          SEA02370
      RETURN                                                            SEA02380
      END                                                               SEA02390
```

```
      SUBROUTINE SPREAD (LIB,LOB,IT)                                    SEA02400
      COMMON CELL(100,100),EF(100,100),PAT(60),                         SEA02410
     2               MAP(60,2),LIM(4),NAT(4),                           SEA02420
     3               MAXX,MINX,MAXY,MINY                                SEA02430
      MAXX=0                                                            SEA02440
      MINX=100                                                          SEA02450
      MAXY=0                                                            SEA02460
      MINY=100                                                          SEA02470
      DO 419 I=1,100                                                    SEA02480
      DO 419 J=1,100                                                    SEA02490
      IF (CELL(J,I).EQ.0.) GO TO 419                                    SEA02500
      DO 418 N=1,IT                                                     SEA02510
      LI=I+MAP(N,1)                                                     SEA02520
      LJ=J+MAP(N,2)                                                     SEA02530
      IF (((I.LT.LIM(1)).AND.(LI.GE.LIM(1)).AND.(NAT(1).EQ.LOB)).OR.    SEA02540
     2    ((I.GT.LIM(2)).AND.(LI.LE.LIM(2)).AND.(NAT(2).EQ.LOB)).OR.    SEA02550
     3    (((LIM(1).LE.I).AND.(LIM(2).GE.I)).AND.                       SEA02560
     4    (((LI.LT.LIM(1)).AND.(NAT(1).EQ.LIB)).OR.                     SEA02570
     5    ((LI.GT.LIM(2)).AND.(NAT(2).EQ.LIB)))))                       SEA02580
     6            LI=I-MAP(N,1)                                         SEA02590
      IF (((J.LT.LIM(3)).AND.(LJ.GE.LIM(3)).AND.(NAT(3).EQ.LOB)).OR.    SEA02600
     2    ((J.GT.LIM(4)).AND.(LJ.LE.LIM(4)).AND.(NAT(4).EQ.LOB)).OR.    SEA02610
     3    (((LIM(3).LE.J).AND.(LIM(4).GE.J)).AND.                       SEA02620
     4    (((LJ.LT.LIM(3)).AND.(NAT(3).EQ.LIB)).OR.                     SEA02630
     5    ((LJ.GT.LIM(4)).AND.(NAT(4).EQ.LIB)))))                       SEA02640
     6            LJ=J-MAP(N,2)                                         SEA02650
      IF ((LI.LT.1).OR.(LI.GT.100).OR.(LJ.LT.1).OR.(LJ.GT.100))         SEA02660
     2  GO TO 418                                                       SEA02670
      EF (LJ,LI)=EF(LJ,LI)+PAT(N)*CELL(J,I)                             SEA02680
  418 CONTINUE                                                          SEA02690
  419 CONTINUE                                                          SEA02700
      DO 518 I=1,100                                                    SEA02710
      DO 518 J=1,100                                                    SEA02720
      CELL(I,J)=EF(I,J)                                                 SEA02730
      IF (CELL(I,J).EQ.0.) GO TO 518                                    SEA02740
      MAXX=MAX0(MAXX,J)                                                 SEA02750
      MINX=MIN0(MINX,J)                                                 SEA02760
      MAXY=MAX0(MAXY,I)                                                 SEA02770
      MINY=MIN0(MINY,I)                                                 SEA02780
  518 CONTINUE                                                          SEA02790
      RETURN                                                            SEA02800
      END                                                               SEA02810
```

```
      SLBRCUTINE FROB(PG,KCUNT,FAC)                                     SEAC282C
      CCMMON CELL(1C0,100),EF(100,100),PAT(60),                         SEAC2830
     2               MAP(60,2),LIM(4),NAT(4),                           SEA02840
     3               MAXX,MINX,MAXY,MINY                                SEA02850
  1CC FORMAT (2X,'AFTER',1X,I2,1X,'PERICDS, PROB DET IS ',G12.5)        SEA02860
      PNCT=0.                                                           SEA02870
      DC 517 I=MINY,MAXY                                                SEA02880
      DO 517 J=MINX,MAXX                                                SEA02890
      PNOT=PNOT+CELL(I,J)*(1.-EXP(-FAC*EF(I,J)))                        SEA0290C
  517 CCNTINUE                                                          SEA02910
      PNOT=1.-PNCT                                                      SEAC292C
      FG=PG*PNOT                                                        SEA02930
      PNOT=1.-PG                                                        SEAC294C
      WRITE (6,100) KCUNT,FNOT                                          SEA02950
      RETURN                                                            SEA02960
      ENC                                                               SEA0297C
```

PROGRAM SRCH2

```
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION NIMB(4)
      DATA LAB,LIB,LOB/1HY,3HREF,3HABS/
   90 FORMAT (2X,'ENTER LIMITS OF TARGET AREA AND TYPES OF BOUNDARIES')
   91 FORMAT (4(I2,A3))
  100 FORMAT (2X,'ENTER LIMITS OF SEARCH AREA')
 1000 FORMAT (4I2)
  101 FORMAT (2X,'HOW MANY VALUES CAN V(X) ASSUME?')
  102 FORMAT (2X,'INVALID IMPUT DATA')
  103 FORMAT (2X,'HOW MANY VALUES CAN V(Y) ASSUME?')
  104 FORMAT (2X,'ENTER THESE VALUES, ONE PER LINE')
  105 FORMAT (2X,'ENTER TRANSITION OF V(X)')
  106 FORMAT (I2,F5.3)
  107 FORMAT (2X,'ENTER TRANSITION OF V(Y)')
  108 FORMAT (2X,'ENTER A PRIORI DISTRIBUTIONS')
  109 FORMAT (2I2,11F5.3)
 1090 FORMAT (2X,'ENTER TOTAL EFFORT AND DETECTION RATE')
 1091 FORMAT (2F5.3)
 1092 FORMAT (2X,'MYOPIC PLAN?')
  110 FORMAT (2X,'ENTER DISTRIBUTION OF SEARCH EFFORT')
  112 FORMAT (2X,'WANT TO CONTINUE?')
  113 FORMAT (2X,'REPEAT LAST ENTRY')
  114 FORMAT (2X,'WANT TO PLAY AGAIN?')
  115 FORMAT (A1)
  180 WRITE (6,90)
      READ (5,91) ((LIM(I),NAT(I)),I=1,4)
      IF ((LIM(1).GE.1).AND.(LIM(2).LE.25).AND.(LIM(3).GE.1).
     2    AND.(LIM(4).LE.25)) GO TO 189
      WRITE (6,102)
      GO TO 180
  189 WRITE (6,100)
      READ (5,1000) (NIMB(J),J=1,4)
      IF ((NIMB(1).GE.1).AND.(NIMB(2).LE.25).AND.(NIMB(3).
     2    GE.1).AND.(NIMB(4).LE.25)) GO TO 200
      WRITE (6,102)
      GO TO 189
  200 MAXSX=-1000
      MINSX=1000
      MAXSY=-1000
      MINSY=1000
  201 WRITE (6,101)
      READ (5,106) IX
      IF (IX.LE.4) GO TO 202
      WRITE (6,102)
      GO TO 201
  202 WRITE (6,104)
```

```
      DO 203 I=1,IX                                                     SEC00490
      READ (5,106) NSX(I)                                               SEC00500
      MAXSX=MAX0(MAXSX,NSX(I))                                          SEC00510
      MINSX=MIN0(MINSX,NSX(I))                                          SEC00520
  203 CONTINUE                                                          SEC00530
  204 WRITE (6,103)                                                     SEC00540
      READ (5,106) IY                                                   SEC00550
      IF (IY.LE.4) GO TO 205                                            SEC00560
      WRITE (6,102)                                                     SEC00570
      GO TO 204                                                         SEC00580
  205 WRITE (6,104)                                                     SEC00590
      DO 206 I=1,IY                                                     SEC00600
      READ (5,106) NSY(I)                                               SEC00610
      MAXSY=MAX0(MAXSY,NSY(I))                                          SEC00620
      MINSY=MIN0(MINSY,NSY(I))                                          SEC00630
  206 CONTINUE                                                          SEC00640
  209 WRITE (6,105)                                                     SEC00650
      DO 208 I=1,10                                                     SEC00660
      IDSX(I)=0                                                         SEC00670
      PDSX(I)=0.                                                        SEC00680
  208 CONTINUE                                                          SEC00690
      EF(17,19)=0.                                                      SEC00700
      INX=1                                                             SEC00710
  211 READ (5,106) IDSX(INX),PDSX(INX)                                  SEC00720
      IF ((IDSX(INX).EQ.0).AND.(PDSX(INX).EQ.0.)) GO TO 219             SEC00730
      EF(17,19)=EF(17,19)+PDSX(INX)                                     SEC00740
      INX=INX+1                                                         SEC00750
      IF (INX.LE.10) GO TO 211                                          SEC00760
  219 IF (ABS(EF(17,19)-1.).LE.1.E-04) GO TO 235                        SEC00770
      WRITE (6,102)                                                     SEC00780
      GO TO 209                                                         SEC00790
  235 WRITE (6,107)                                                     SEC00800
      INX=INX-1                                                         SEC00810
      DO 236 I=1,10                                                     SEC00820
      IDSY(I)=0                                                         SEC00830
      PDSY(I)=0.                                                        SEC00840
  236 CONTINUE                                                          SEC00850
      EF(21,25)=0.                                                      SEC00860
      INY=1                                                             SEC00870
  237 READ (5,106) IDSY(INY),PDSY(INY)                                  SEC00880
      IF ((IDSY(INY).EQ.0).AND.(PDSY(INY).EQ.0.)) GO TO 239             SEC00890
      EF(21,25)=EF(21,25)+PDSY(INY)                                     SEC00900
      INY=INY+1                                                         SEC00910
      IF (INY.LE.10) GO TO 237                                          SEC00920
  239 IF (ABS(EF(21,25)-1.).LE.1.E-04) GO TO 253                        SEC00930
      WRITE (6,102)                                                     SEC00940
      GO TO 235                                                         SEC00950
  253 EF(3,3)=0.                                                        SEC00960
```

```
      INY=INY-1                                                         SEC00970
      DO 2660 I=1,25                                                    SEC00980
      DO 2660 J=1,25                                                    SEC00990
      DO 2660 K=1,4                                                     SEC01000
      DO 2660 L=1,4                                                     SEC01010
      CELL(I,J,K,L)=0.                                                  SEC01020
 2660 CONTINUE                                                          SEC01030
      EF(20,20)=0.                                                      SEC01040
      MAXX=0                                                            SEC01050
      MINX=100                                                          SEC01060
      MAXY=0                                                            SEC01070
      MINY=100                                                          SEC01080
      WRITE (6,108)                                                     SEC01090
  254 EF(3,3)=EF(3,3)+EF(20,20)                                         SEC01100
      READ (5,109) I,J,EF(20,20),(EF(1,K),K=1,IX),(EF(2,L),L=1,IY)      SEC01110
      IF ((I.EQ.0).AND.(J.EQ.0).AND.(EF(20,20).EQ.0.)) GO TO 262        SEC01120
      EF(5,2)=0.                                                        SEC01130
      DO 259 M=1,IY                                                     SEC01140
      EF(5,2)=EF(5,2)+EF(2,M)                                           SEC01150
      EF(5,1)=0.                                                        SEC01160
      DO 259 N=1,IX                                                     SEC01170
      EF(5,1)=EF(5,1)+EF(1,N)                                           SEC01180
      CELL(J,I,M,N)=EF(20,20)*EF(2,M)*EF(1,N)                           SEC01190
  259 CONTINUE                                                          SEC01200
      IF ((ABS(EF(5,1)-1.).GT.1.0E-04).OR.                              SEC01210
     2    (ABS(EF(5,2)-1.).GT.1.0E-04)) GO TO 260                       SEC01220
      MAXX=MAX0(MAXX,I)                                                 SEC01230
      MINX=MIN0(MINX,I)                                                 SEC01240
      MAXY=MAX0(MAXY,J)                                                 SEC01250
      MINY=MIN0(MINY,J)                                                 SEC01260
      GO TO 254                                                         SEC01270
  260 EF(20,20)=0.                                                      SEC01280
      DO 261 M=1,4                                                      SEC01290
      EF(1,M)=0.                                                        SEC01300
      EF(2,M)=0.                                                        SEC01310
      DO 261 N=1,4                                                      SEC01320
      CELL(I,J,M,N)=0.                                                  SEC01330
  261 CONTINUE                                                          SEC01340
      WRITE (6,102)                                                     SEC01350
      WRITE (6,113)                                                     SEC01360
      GO TO 254                                                         SEC01370
  262 IF (ABS(EF(3,3)-1.).LE.1.0E-04) GO TO 264                         SEC01380
      DO 263 I=1,25                                                     SEC01390
      DO 263 J=1,25                                                     SEC01400
      DO 263 K=1,4                                                      SEC01410
      DO 263 L=1,4                                                      SEC01420
      CELL(I,J,K,L)=0.                                                  SEC01430
  263 CONTINUE                                                          SEC01440
```

```
      WRITE (6,102)                                                     SEC01450
      GO TO 253                                                         SEC01460
  264 KOUNT=1                                                           SEC01470
      PG=1.                                                             SEC01480
  265 CALL TABLE (IX,IY)                                                SEC01490
      WRITE (6,1090)                                                    SEC01500
      READ (5,1091) A,FAC                                               SEC01510
      IF (FAC.LT.1.E-05) FAC=1.E-05                                     SEC01520
      WRITE (6,1092)                                                    SEC01530
      READ (5,115) IANS                                                 SEC01540
      IF (IANS.NE.LAB) GO TO 2067                                       SEC01550
      CALL MYOPIC (A,FAC,IX,IY,NIMB)                                    SEC01560
      GO TO 281                                                         SEC01570
 2067 TOT=0.                                                            SEC01580
      DO 266 I=1,25                                                     SEC01590
      DO 266 J=1,25                                                     SEC01600
      EF(I,J)=0.                                                        SEC01610
  266 CONTINUE                                                          SEC01620
      WRITE (6,110)                                                     SEC01630
  267 READ (5,109) I,J,EF(J,I)                                          SEC01640
      IF ((I.EQ.0).AND.(J.EQ.0).AND.(EF(J,I).EQ.0.)) GO TO 269          SEC01650
      TOT=TOT+EF(J,I)                                                   SEC01660
      EF(J,I)=EF(J,I)*FAC                                               SEC01670
      GO TO 267                                                         SEC01680
  269 IF (ABS(TOT-A).LE.1.E-03) GO TO 281                               SEC01690
      WRITE (6,102)                                                     SEC01700
      GO TO 2067                                                        SEC01710
  281 CALL PROB (PG,KOUNT,IX,IY)                                        SEC01720
      WRITE (6,112)                                                     SEC01730
      READ (5,115) IANS                                                 SEC01740
      IF (IANS.NE.LAB) GO TO 283                                        SEC01750
      CALL UPDATE (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,LIB,LCB)       SEC01760
      KOUNT=KOUNT+1                                                     SEC01770
      GO TO 265                                                         SEC01780
  283 WRITE (6,114)                                                     SEC01790
      READ (5,115) IANS                                                 SEC01800
      IF (IANS.NE.LAB) STOP                                             SEC01810
      GO TO 180                                                         SEC01820
      END                                                               SEC01830
```

```
      SUBROUTINE MYOPIC (A,FAC,IX,IY,NIMB)                                      SEC01840
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),                       SEC01850
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),                     SEC01860
     3       MAXX,MINX,MAXY,MINY                                                SEC01870
      DIMENSION TCELL(25,25),ICELL(25,25),NIMB(4)                               SEC01880
      DATA INDIA/1HY/                                                           SEC01890
  101 FORMAT (2X,'WANT TO KNOW DISTRIBUTION OF EFFORT?')                        SEC01900
  102 FORMAT (A1)                                                               SEC01910
  103 FORMAT (2X,'  CELL    EFFORT')                                            SEC01920
  104 FORMAT (2X,I3,1X,I3,3X,F6.4)                                              SEC01930
   99 DO 190 I=MINY,MAXY                                                        SEC01940
      DO 190 J=MINX,MAXX                                                        SEC01950
      TCELL(I,J)=0.                                                             SEC01960
      DO 190 K=1,IY                                                             SEC01970
      DO 190 L=1,IX                                                             SEC01980
      TCELL(I,J)=TCELL(I,J)+CELL(I,J,K,L)                                       SEC01990
  190 CONTINUE                                                                  SEC02000
  200 DO 201 I=MINY,MAXY                                                        SEC02010
      DO 201 J=MINX,MAXX                                                        SEC02020
      ICELL(I,J)=0                                                              SEC02030
  201 CONTINUE                                                                  SEC02040
  226 DO 231 I=1,25                                                             SEC02050
      DO 231 J=1,25                                                             SEC02060
      EF(I,J)=0.                                                                SEC02070
  231 CONTINUE                                                                  SEC02080
  241 IMIN=0                                                                    SEC02090
      JMIN=0                                                                    SEC02100
      B=1.                                                                      SEC02110
      N=0                                                                       SEC02120
      PMIN=1.                                                                   SEC02130
      IFLAG=0                                                                   SEC02140
      DO 247 I=MINY,MAXY                                                        SEC02150
      DO 247 J=MINX,MAXX                                                        SEC02160
      IF ((TCELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3))             SEC02170
     2   .OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))                SEC02180
     3   GO TO 247                                                              SEC02190
      IF ((TCELL(I,J).GE.PMIN).OR.(IFLAG.EQ.1)) GO TO 243                       SEC02200
      PMIN=TCELL(I,J)                                                           SEC02210
      IMIN=I                                                                    SEC02220
      JMIN=J                                                                    SEC02230
  243 CONTINUE                                                                  SEC02240
      IF ((TCELL(I,J).LE.PMIN).AND.(IFLAG.EQ.1)) ICELL(I,J)=1                   SEC02250
      IF (IFLAG.EQ.1) GO TO 247                                                 SEC02260
      N=N+1                                                                     SEC02270
      B=(B**(1./(FAC*FLOAT(N))))**((FAC*FLOAT(N-1)))                            SEC02280
      B=B*TCELL(I,J)**(1./(FAC*FLOAT(N)))                                       SEC02290
      REF=EXP(A/FLOAT(N))                                                       SEC02300
      BEF=B/(PMIN**(1./FAC))                                                    SEC02310
```

```
      IF (REF.GE.REF) GO TO 247                                           SEC02320
      ICELL(IMIN,JMIN)=1                                                   SEC02330
      IFLAG=1                                                              SEC02340
  247 CONTINUE                                                             SEC02350
      IF (IFLAG.EQ.0) GO TO 248                                            SEC02360
      GO TO 241                                                            SEC02370
  248 DO 251 I=MINY,MAXY                                                   SEC02380
      DO 251 J=MINX,MAXX                                                   SEC02390
      IF ((TCELL(I,J).EQ.0.).OR.(ICELL(I,J).EQ.1).OR.(I.LT.NIMB(3)).      SEC02400
     2    OR.(I.GT.NIMB(4)).OR.(J.LT.NIMB(1)).OR.(J.GT.NIMB(2)))          SEC02410
     3     GO TO 251                                                       SEC02420
      PROB=B**(FAC*FLOAT(N))                                               SEC02430
      EF(I,J)=(ALOG(TCELL(I,J))/FAC)+(A/FLOAT(N))-                         SEC02440
     2        (ALOG(PROB)/(FAC*FLOAT(N)))                                  SEC02450
  251 CONTINUE                                                             SEC02460
      WRITE (6,101)                                                        SEC02470
      READ (5,102) IPU                                                     SEC02480
      IF (IPU.NE.INDIA) RETURN                                             SEC02490
      WRITE (6,103)                                                        SEC02500
      DO 281 I=MINY,MAXY                                                   SEC02510
      DO 281 J=MINX,MAXX                                                   SEC02520
      IF (EF(I,J).EQ.0.) GO TO 281                                         SEC02530
      WRITE (6,104) J,I,EF(I,J)                                            SEC02540
  281 CONTINUE                                                             SEC02550
      RETURN                                                               SEC02560
      END                                                                  SEC02570
```

```
      SUBROUTINE TABLE (IX,IY)
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION ICELL(25),IMBOL(15)
      DATA IMBOL/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,
     2           1H*,1H.,1H-,1HY/
  100 FORMAT (2X,'RANGE OF PROBABILITIES',2(1X,G12.5))
  101 FORMAT (2X,I3,'/ ',100A1)
  102 FORMAT (6X,I2,9(8X,I2))
  103 FORMAT (7X,100I1)
  104 FORMAT (7X,100A1)
      DO 201 I=1,25
      DO 201 J=1,25
      EF(I,J)=0.
      DO 201 K=1,IY
      DO 201 L=1,IX
      EF(I,J)=EF(I,J)+CELL(I,J,K,L)
  201 CONTINUE
      SMALL=1.
      BIG=0.
      DO 217 I=MINY,MAXY
      DO 217 J=MINX,MAXX
      IF ((EF(I,J).NE.0.).AND.(EF(I,J).LT.SMALL)) SMALL=EF(I,J)
      IF (EF(I,J).GT.BIG) BIG=EF(I,J)
  217 CONTINUE
      WRITE (6,100) SMALL,BIG
      IF ((BIG-SMALL).LT.1.E-5) SMALL=0.
      DO 417 I=1,25
      ICELL(I)=MINX+(I-1)*10
      IF (ICELL(I).GT.MAXX) GO TO 418
  417 CONTINUE
  418 I=I-1
      WRITE (6,102) (ICELL(J),J=1,I)
      LA=MAXX-MINX+1
      DO 517 N=1,LA
      ICELL(N)=MOD(N-1+MINX,10)
  517 CONTINUE
      WRITE (6,103) (ICELL(I),I=1,LA)
      DO 617 I=1,LA
      ICELL(I)=IMBOL(13)
  617 CONTINUE
      WRITE (6,104) (ICELL(I),I=1,LA)
      DO 817 I=MINY,MAXY
      DO 717 J=MINX,MAXX
       ICELL(J)=IMBOL(1.+
     2   IFIX(10.-SQRT(100.-(EF(I,J)-SMALL)/(BIG-SMALL)*100.)))
      IF (EF(I,J).EQ.0.) ICELL(J)=IMBOL(12)
```

```
717 CONTINUE                                            SEC03060
    WRITE (6,101) I,(ICELL(J),J=MINX,MAXX)              SEC03070
817 CONTINUE                                            SEC03080
    RETURN                                              SEC03090
    END                                                 SEC03100
```

```
      SUBROUTINE PROB (PG,KOUNT,IX,IY)                                  SEC03110
      COMMON CELL(25,25,4,4),EF(25,25),PDSX(10),PDSY(10),               SEC03120
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),             SEC03130
     3       MAXX,MINX,MAXY,MINY                                        SEC03140
  101 FORMAT (2X,'AFTER',1X,I2,1X,'PERIODS, PROB DET IS ',F6.4)         SEC03150
      PNOT=1.                                                           SEC03160
      DO 219 I=1,25                                                     SEC03170
      DO 219 J=1,25                                                     SEC03180
      A=0.                                                              SEC03190
      DO 217 K=1,IY                                                     SEC03200
      DO 217 L=1,IX                                                     SEC03210
      A=A+CELL(I,J,K,L)                                                 SEC03220
  217 CONTINUE                                                          SEC03230
      PNOT=PNOT-A*(1.-EXP(-EF(I,J)))                                    SEC03240
  219 CONTINUE                                                          SEC03250
      PG=PG*PNOT                                                        SEC03260
      PNOT=1.-PG                                                        SEC03270
      WRITE (6,101) KOUNT,PNOT                                          SEC03280
      RETURN                                                            SEC03290
      END                                                               SEC03300
```

```
      SUBROUTINE UPDATE (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,
     2                   LIB,LOB)
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION TCELL(25,25),PVY(10),PVX(10)
      DENOM=0.
      DO 319 I=1,25
      DO 319 J=1,25
      TCELL(I,J)=0.
      DO 318 K=1,IY
      DO 318 L=1,IX
      TCELL(I,J)=TCELL(I,J)+CELL(I,J,K,L)
  318 CONTINUE
      DENOM=DENOM+TCELL(I,J)*EXP(-EF(I,J))
  319 CONTINUE
      DO 351 I=1,25
      DO 351 J=1,25
      DO 339 L=1,IX
      PVX(L)=0.
      DO 338 K=1,IY
      PVX(L)=PVX(L)+CELL(I,J,K,L)
  338 CONTINUE
      IF (TCELL(I,J).EQ.0.) GO TO 339
      PVX(L)=PVX(L)/TCELL(I,J)
  339 CONTINUE
      DO 345 K=1,IY
      PVY(K)=0.
      DO 341 L=1,IX
      PVY(K)=PVY(K)+CELL(I,J,K,L)
  341 CONTINUE
      IF (TCELL(I,J).EQ.0.) GO TO 345
      PVY(K)=PVY(K)/TCELL(I,J)
  345 CONTINUE
      TCELL(I,J)=TCELL(I,J)*EXP(-EF(I,J))/DENOM
      DO 347 K=1,IY
      DO 347 L=1,IX
      CELL(I,J,K,L)=TCELL(I,J)*PVY(K)*PVX(L)
  347 CONTINUE
  351 CONTINUE
      CALL SPREAD (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,LIB,LOB)
      RETURN
      END
```

```
      SUBROUTINE SPREAD (IX,IY,INX,INY,MAXSX,MINSX,MAXSY,MINSY,
     2                   LIB,LOB)
      COMMON CELL(25,25,4,4),EF(25,25),PCSX(10),PCSY(10),
     2       NSX(4),NSY(4),IDSX(10),IDSY(10),LIM(4),NAT(4),
     3       MAXX,MINX,MAXY,MINY
      DIMENSION TCELL(25,25,4,4),INAX(10,4),INAY(10,4)
      DO 201 I=1,25
      DO 201 J=1,25
      DO 201 K=1,IY
      DO 201 L=1,IX
      TCELL(I,J,K,L)=0.
  201 CONTINUE
      DO 231 I=1,25
      DO 231 J=1,25
      DO 231 K=1,IY
      DO 231 L=1,IX
      LI=I+NSX(L)
      LJ=J+NSY(K)
      IF (((I.LT.LIM(1)).AND.(LI.GE.LIM(1)).AND.(NAT(1).EQ.LOB)).OR.
     2    ((I.GT.LIM(2)).AND.(LI.LE.LIM(2)).AND.(NAT(2).EQ.LOB)).OR.
     3    (((LIM(1).LE.I).AND.(LIM(2).GE.I)).AND.
     4    (((LI.LT.LIM(1)).AND.(NAT(1).EQ.LIB)).OR.
     5    ((LI.GT.LIM(2)).AND.(NAT(2).EQ.LIB)))))
     6       LI=I-NSX(L)
      IF (((J.LT.LIM(3)).AND.(LJ.GE.LIM(3)).AND.(NAT(3).EQ.LOB)).OR.
     2    ((J.GT.LIM(4)).AND.(LJ.LE.LIM(4)).AND.(NAT(4).EQ.LOB)).OR.
     3    (((LIM(3).LE.J).AND.(LIM(4).GE.J)).AND.
     4    (((LJ.LT.LIM(3)).AND.(NAT(3).EQ.LIB)).OR.
     5    ((LJ.GT.LIM(4)).AND.(NAT(4).EQ.LIB)))))
     6       LJ=J-NSY(K)
      IF ((LI.LT.1).OR.(LJ.LT.1).OR.
     2    (LI.GT.25).OR.(LJ.GT.25)) GO TO 231
      TCELL(LJ,LI,K,L)=TCELL(LJ,LI,K,L)+CELL(J,I,K,L)
  231 CONTINUE
      MAXX=0
      MINX=30
      MAXY=0
      MINY=30
      DO 251 I=1,25
      DO 251 J=1,25
      DO 251 K=1,IY
      DO 251 L=1,IX
      IF (TCELL(I,J,K,L).EQ.0.) GO TO 249
      MAXX=MAX0(MAXX,J)
      MINX=MIN0(MINX,J)
      MAXY=MAX0(MAXY,I)
      MINY=MIN0(MINY,I)
  249 CELL(I,J,K,L)=0.
```

```
251 CONTINUE                                                            SEC04220
    DO 701 I=1,INX                                                      SEC04230
    DO 701 J=1,IX                                                       SEC04240
    INAX(I,J)=MAXO(MINSX,MINO(MAXSX,NSX(J)+IDSX(I)))                    SEC04250
701 CONTINUE                                                            SEC04260
    DO 702 I=1,INY                                                      SEC04270
    DO 702 J=1,IY                                                       SEC04280
    INAY(I,J)=MAXO(MINSY,MINO(MAXSY,NSY(J)+IDSY(I)))                    SEC04290
702 CONTINUE                                                            SEC04300
    DO 710 I=MINY,MAXY                                                  SEC04310
    DO 710 J=MINX,MAXX                                                  SEC04320
    DO 710 IINX=1,INX                                                   SEC04330
    DO 710 IIX=1,IX                                                     SEC04340
    DO 705 N=1,IX                                                       SEC04350
    IF (INAX(IINX,IIX).EQ.NSX(N)) GO TO 706                             SEC04360
705 CONTINUE                                                            SEC04370
706 DO 710 IINY=1,INY                                                   SEC04380
    DO 710 IIY=1,IY                                                     SEC04390
    DO 707 M=1,IY                                                       SEC04400
    IF (INAY(IINY,IIY).EQ.NSY(M)) GO TO 708                             SEC04410
707 CONTINUE                                                            SEC04420
708 CELL(I,J,M,N)=CELL(I,J,M,N)+TCELL(I,J,IIY,IIX)*                     SEC04430
   2             PDSY(IINY)*PDSX(IINX)                                  SEC04440
710 CONTINUE                                                            SEC04450
    RETURN                                                              SEC04460
    END                                                                 SEC04470
```

LIST OF REFERENCES

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